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Wing Structure Static Analysis using Superelement

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Abstract

This paper describes the use of superelement for the stress and deflection analysis of a typical fighter wing structure. Three methods of analyses were carried out and compared: practical/theoretical analysis; finite element analysis with the conventional element modeling approach; and finite element analysis with the superelement modeling. Finite element models of the wing were developed. NASTRAN FE software was used for finite element analysis. CQUAD4 and BAR2 elements represent the individual components of the wing such as the skin and stringers. In superelement approach, the wing was divided to four (4) substructures known as superelements. Wing loading at 1-g flight condition was assumed for analysis. For all these methods, the direct stress and deflection are sought and to be compared. Result shows a good agreement between the three methods.

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Keywords: Wing structure; finite element analysis; superelement analysis.

1. Introduction

The Finite Element method synthesizes complicated structural systems as a connected collection of objects, called finite elements that embody local physical laws [1]. The use of finite element analysis have made its way to a stage where they are widely used in various engineering applications and are improving steadily over the past decade. Engineers are able to predict the behavior of these elements as it would be in the form of mathematical models which will then be solved, resulting in a set of linear algebraic equations. There are many references that can be found to better understand the concept of using finite element as an analysis tool [1-2]. It is a form of numerical analysis which can be used for stress prediction and structural optimization [3-4].

Superelements are defined as grouping of finite elements which, upon assembly, maybe considered as an individual element for computational purposes. It is an analysis procedure that supports collaborative analysis and is very useful for large models that are developed by different organizations. Superelement is a form of sub structuring, that is, the model is divided into a series of components (superelements) for example, spars, ribs and panels to be regarded as individual superelements. Each of these will be processed independently resulting in a set of reduced matrices that describes the behaviour of the superelement as seen by the rest of the structure. An example is illustrated in Fig 1. Level two substructure in that model can be regarded as a superelement that encompasses individual (conventional) elements.

These reduce matrices for the individual superelements are combined to form an assembly solution. The results of the assembly are then used to perform data recovery (calculations of stresses, displacement etc) for the superelements [5]. Superelements allow a big, complex structure to be analyzed, by dividing this structure to individual components. These

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individual components will be analyzed and then assembled together to produce a complete analysis results.

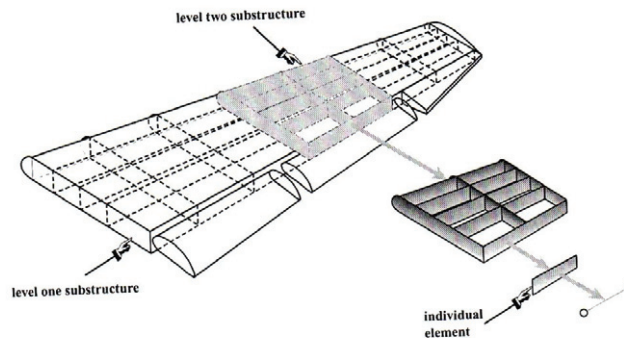


Fig. 1. Example of Superelements.

Superelements can consist of physical data (elements and grid points) or can be defined as an image of another superelement or as an external superelement (a set of matrices from an external source to be attached to the model). The image superelement can save processing time in that they are able to use the stiffness, mass and damping from their primary superelement, which reduces the amount of calculations needed. Full data recovery is available for image superelements. An image superelement can be an identical image or a mirror image copy of the primary. The other type of superelement is the external superelement where a part of a model is represented by using matrices of an outside source. For these matrices, no internal geometry information is available only the grid points to which the matrices are attached are known.

Within the aircraft industry, the application of finite element analysis has mainly concentrated on providing an insight into both detail and structural behaviour. The testing of structures still forms a large part of the design and qualification process, with analysis providing additional information to support these activities [6]. Superelements had been described to be applicable for various analytical domains [7]. It had been reported for example that, superelements were used in the accurate enforced motion analysis [8]. Crack propagation analysis had been performed making use Nastran superelement capacity [9]. Dynamic analysis of a gas turbine engine rotor had been conducted using superelement modelling [10]. Recently, M.T. Ahmadian et.al. developed and applied a new tapered superelement for analysis of revolving geometries under lateral, axial and torsional loads [11]. Reduced superelement modelling was used by B.P. Nortier et.al to model and analyze complex foundations structures of offshore turbine installation [12]. Sarvi and Ahmadian introduced a new spherical superelements for modelling and analysis of hollow spherical structures such as biological cells and pressure vessels [13].

The finite element model of a typical wing structure was developed in this paper. Three methods of analysis were carried out on the same structure and compared. Those are the theoretical analysis, the finite element analysis with the conventional meshing approach and the finite element analysis with the superelement meshing.

2. Methodology

Fig 2 shows the layout of an aircraft with the (right) wing shown. Methods of analysis is shown in Fig 3.

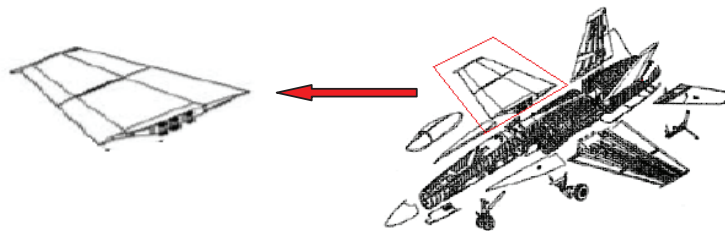


Fig. 2. Aircraft Layout.

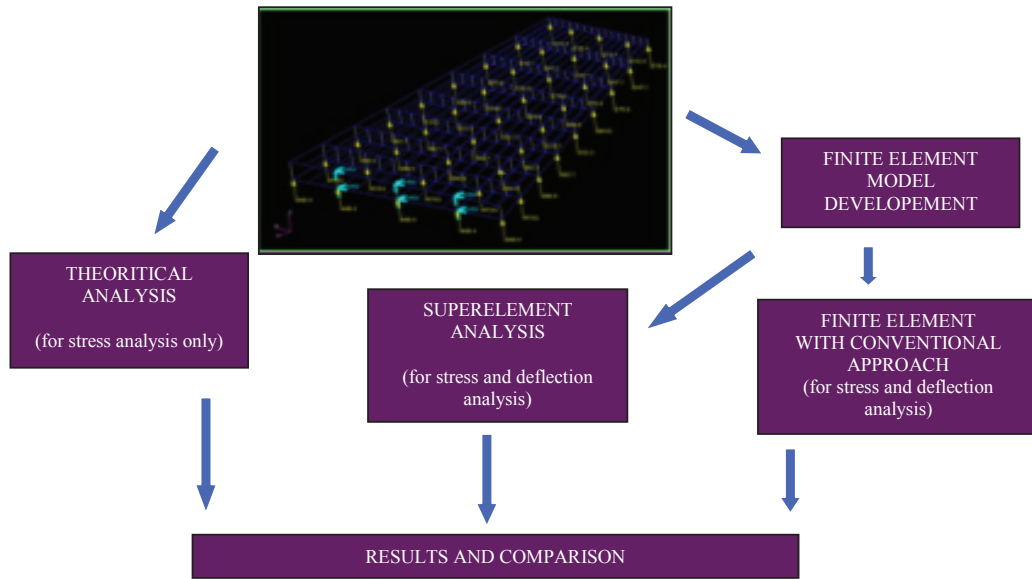


Fig. 3. Methods of Analysis.

3. Theoretical stress analysis

Fig 4 describes the sections at which all three analyses would be carried out and compared. The results are referred to this figure.

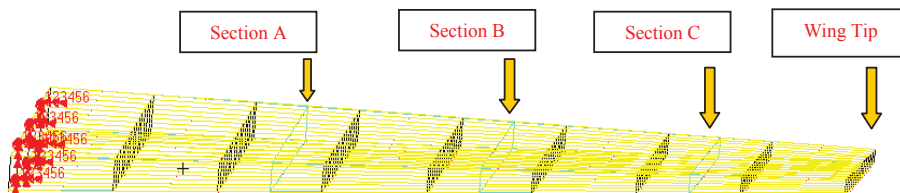


Fig. 4. Sections of Analysis.

Stress analysis calculation is based on the general bending (flexural) stress:

$$\sigma = \frac{My}{I} \quad (1)$$

where M = bending moment at the respective section
 I = second moment of area of respective section
 y = distance from the neutral axis to the point of interest

4. Finite element model (Conventional Approach)

4.1 Wing Loading at 1-g Symmetrical Level Flight Condition

Total force acting on the wing is equal to the total lift forces minus the total inertia forces. The inertia forces may consists of the weight of fuel, the weight of weapons, and the weight of the structure. It was assumed that the total force acting at the wing is equal to 15000N. The force is distributed in such a manner where the load magnitude is higher at the region closest to the fuselage and continuously decreasing outboard to the wing tip. For 9 rib sections along the span of the wing, Fig 5, the forces are distributed according to the chord length of that particular section. If the chord length is higher, then the

forces applied would be higher. The longest chord closest to the fuselage is 2209 mm and the length of the chord nearer to the tip is 1075.6 mm.

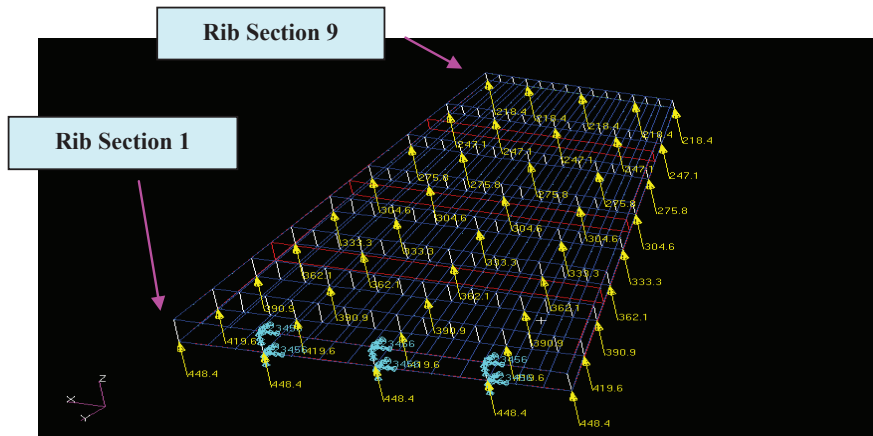


Fig. 5. Wing Model Showing Points of Loads.

4.2 Finite Element Model of the Wing

The finite element model of the wing, Fig 6, was created with the following properties [14]:

- The upper skin, lower skin, ribs surfaces, leading edge, trailing edge and the wing tip are comprised of CQUAD4 elements (a quadrilateral flat shell connecting four grid points).
- CSHEAR (a four-grid element that supports shear and extensional force) to represent the forward, center and aft spar.
- BAR2 element to represent ribs' stiffeners with 1-d rod property of area 80mm^2 (representing the effective areas of the ribs stiffeners). BAR2 element is a general purpose beam that supports tension and compression, torsion, bending in two perpendicular planes, and shear in two perpendicular planes.

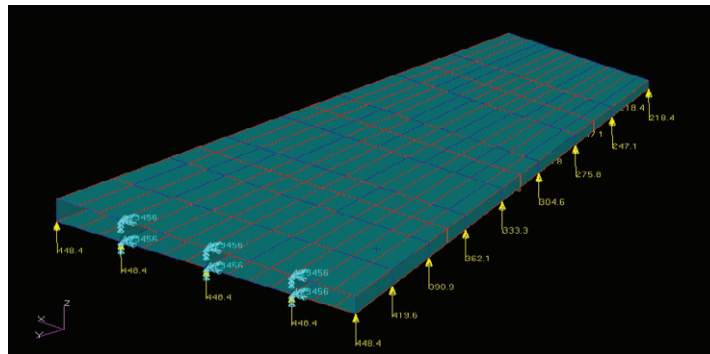


Fig. 6. Finite Element Model of the Wing.

- The ribs surfaces are presented by shell property. The PSHELL entry defines the membranes, bending, transverse shear, and coupling properties of thin plate and shell elements.
- The material used for this analysis is Aluminum Alloy 7000 series with a Young Modulus of 72 GN/m^2 and Poisson Ratio of 0.33. The model is fixed at the points representing the location of the lugs and loads are applied accordingly.

5. Superelement application

Fig 7 shows the superelement concept of modelling. By creating two superelements, the 5 nodes of the bar is now reduced to three nodes. This means that a 3×3 matrices is formed instead of a 5×5 . This is the first step towards using the static condensation technique [5] in solving this problem.

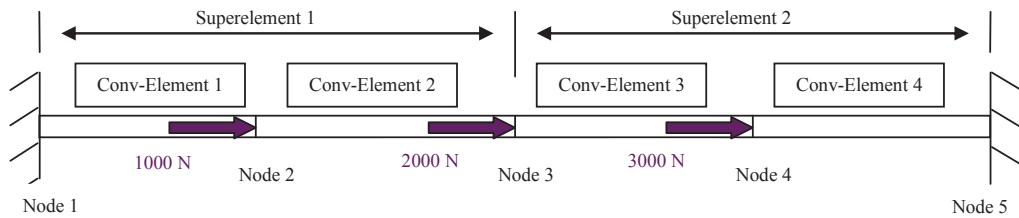


Fig. 7. Superelement concept

The same principle is applied to the wing structure. For the superelement analysis, the wing structure is divided to four (4) superelements. How the superelement selection/division of the wing structure is shown in Fig 8 to Fig 11. Once the wing structure has been divided to these four (4) superelements, analysis is carried out and the results will be compared to the theoretical and finite element analysis with the conventional selection approach.

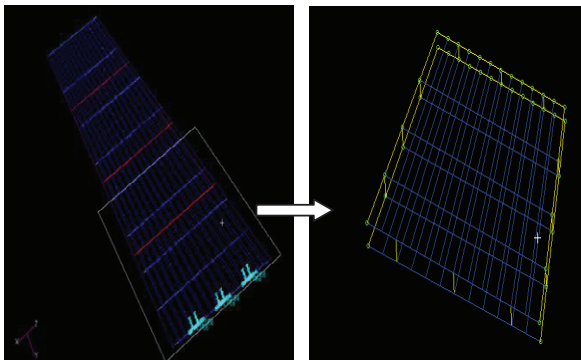


Fig. 8. Wing Superelement 1.

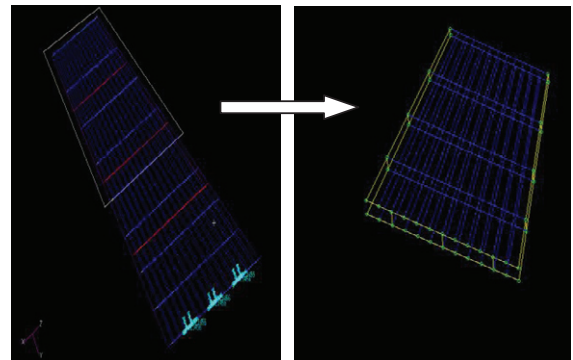


Fig. 9. Wing Superelement 2.

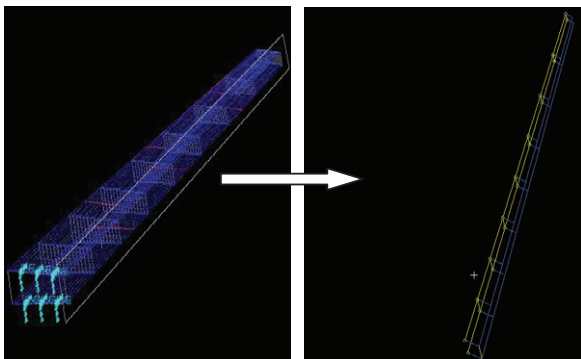


Fig. 10. Wing Superelement 3.

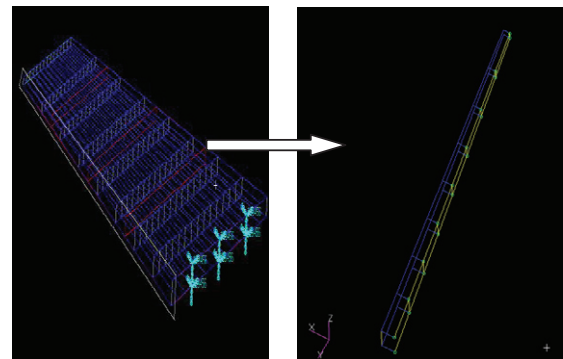


Fig. 11. Wing Superelement 4

6.0 Results

Forces acting at rib-section 1 to 9 along the wing are shown in Table 1.

Table 1. Forces Acting Along the Wing.

Rib Section	1	2	3	4	5	6	7	8	9
Force [N]	448.4	419.6	310.9	362.1	333.3	304.6	275.6	247.1	218.4

The theoretical and finite element analysis results for the stress analysis are shown in Table 2.

Table 2. Direct Stress along the wing.

	Section A (N/mm ²)	Section B (N/mm ²)	Section C (N/mm ²)	Wing Tip (N/mm ²)
Theoretical	21.17	12.14	4.3	0
FEA (conventional)	21.12	12.04	4.13	0.2
FEA (superelement)	21.12	12.04	4.13	0.2

Fig 12 below shows the displacement contour using finite element analysis.

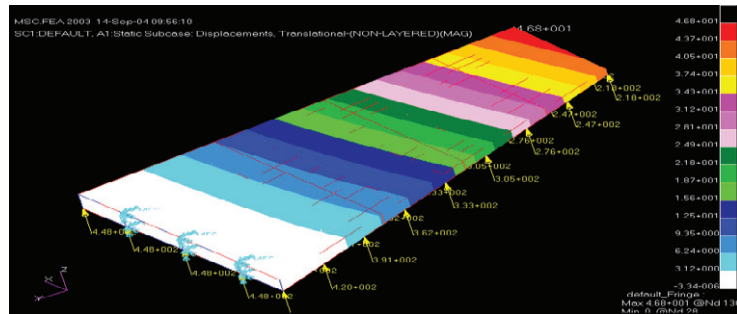


Fig. 12. Displacement Distribution.

The displacement values are shown in Table 3.

Table 3. Displacement along the wing.

	Section A (mm)	Section B (mm)	Section C (mm)	Wing Tip (mm)
FEA (conventional)	7.8	18.7	32.8	45.3
FEA (superelement)	7.8	18.7	32.8	45.3

Fig 13 shows the stress comparison between theoretical, finite element analysis with the conventional meshing, and the finite element analysis with the superelement. Fig 14 shows the comparison for displacements. The difference between the theoretical analysis and the finite element analysis is minimal. The finite element analysis with the conventional approach and the superelement approach give the same results.

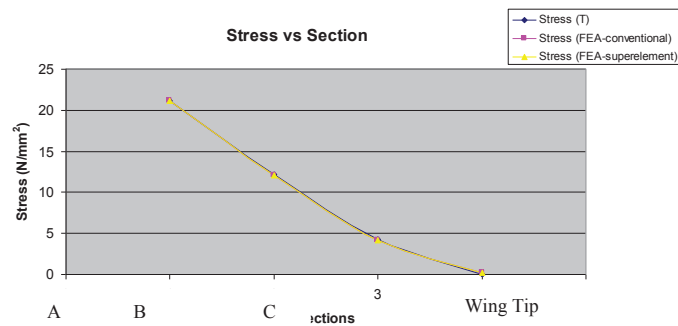


Fig. 13. Stress comparison between the three approaches.

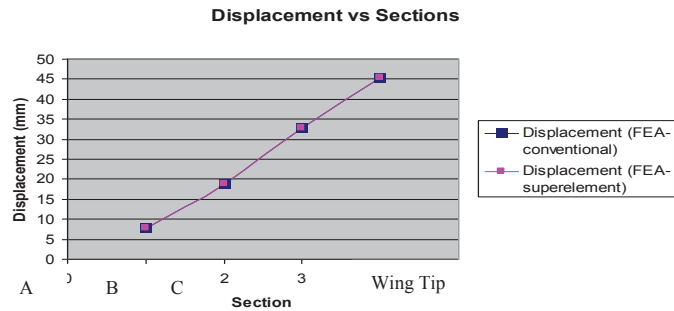


Fig. 14. Displacements comparison between FE conventional meshing and superelement.

7.0 Conclusion

Three methods of analysis were performed on a typical aircraft wing structure to obtain the stress and deflection values. They are the theoretical approach for stress analysis only, the finite element analysis with the conventional approach and the finite element analysis with the superelement approach. The comparison of the stress values between the theoretical approach and the finite element analysis approaches shows minimal errors. The comparison of the stress values between the finite element analysis with conventional approach and finite element analysis with superelement approach shows the same results. The finite element analysis with conventional approach and superelement approach shows the same results for the deflection values. This proves that that the superelement approach does not alter the values obtained from the conventional finite element approach.

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